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# Pre-race strategies to maintain and enhance the physiological effects of a warm-up in 100m freestyle performance

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## ABSTRACT

This study investigated the effects of a plyometric protocol and passive heat maintenance strategy on 100m freestyle performance. Twelve subjects (age 15.5 ± 2.4 years; bodyweight 63.4 ± 9.2kg; height 162 ± 9.1cm) (6 males and 6 females) volunteered and provided written consent, which was approved by the university ethics committee. Subjects completed two familiarisation sessions, one involving a plyometric protocol with countermovement jumps taken at baseline and immediately, 2, 4, 6, 8 and 10 minutes post to determine individualised recovery time. Subjects completed four different trials in a counterbalanced design, each consisted of a 15-minute pool warm up with a 10-minute recovery period before entering a simulated call room. Subjects completed the following trials prior to a 100m time trial; plyometric protocol at individualised times (PLYO), plyometric protocol at individualised times with the use of a blizzard heat jacket (PHEAT), the use of a blizzard heat jacket (HEAT) and a control trial (CONTROL). Subject core body temperatures ($T_{Core}$) were taken at baseline, post pool warm up and pre time trial. The plyometric protocol involved performing 2 sets of pogos (5 reps), alternate leg bounding (10m), single leg hops (5 each leg) and depth jump from 12-inch box (3 reps). Repeated measures ANOVA found PHEAT (56.33 ± 2.86s) significantly faster than CONTROL (57.48 ± 2.57s) ($p = 0.009$) and HEAT (57.26 ± 3.09s) ($p = 0.038$). Spearman's correlation tests discovered negative correlations between $T_{Core}$ and 100m times in all trials (PHEAT, $P = 0.894$; PLYO, $P = 0.734$; HEAT, $P = 0.023$; CONTROL, $P = 0.493$). In summary, completing a plyometric protocol along with the use of a blizzard heat jacket pre race may enhance subsequent 100m freestyle performance.

## KEY WORDS

**Post-activation potentiation, passive heat maintenance, plyometrics, blizzard heat jackets.**

## INTRODUCTION

One of the key aims of an athlete's warm up is to physiologically prepare themselves for competition (2). Swimming competitions around the world must follow the rules and standards set by Fédération Internationale de Natation (FINA) (12) for race times achieved to be legalised. FINA rule SW 3.2.5 states that all swimmers must report to the call room no later than 20 minutes prior to the start of their event for inspection by Technical Officials. This rule poses an issue for swimmers in regards to the length of time between the completion of their warm up and their race. Bishop (2) states how a recovery period of no more than 15 minutes is optimal for phosphocreatine (PCr) re-synthesis and maintaining the enhanced muscle temperature ($T_m$) whilst improving short-term performance.

There are potential strategies that may prevent the physiological return to baseline metabolic levels within the 20 minute time period whereby a swimmer is in the call room. One pre-competition strategy that has been well researched is the phenomenon that is post-activation potentiation (PAP) (2, 25, 26, 45, 46, 49, 56). It involves performing a conditioning activity typically with maximal or near maximal intensity and produces an acute increase in muscular power that has been found to improve performance (45, 49). A primary response to a PAP protocol is the enhancement of an individual's rate of force development (RFD), which is the speed at which the contractile elements of musculature can produce force, which may then enhance performance in explosive activities (53). Although no research has discovered a PAP protocol to acutely enhance the force capabilities of an individual, research has demonstrated that PAP protocols can acutely enhance the velocity at which a specific force is applied (42, 47). Sale (42) states that the force-velocity curve becomes less concave, shifting to the right following a PAP protocol. This can result in greater velocities for a specific force or vice versa (42).

The literature informs us that there are two primary physiological mechanisms that underpin PAP. Firstly, the phosphorylation of myosin regulatory light chains (RLC) and secondly, the increased recruitment of higher order motor units (22). A RLC has a specific binding site for a phosphate molecule. During a muscular contraction, there is a release of $Ca^+$ molecules that in turn activate the enzyme, myosin light chain kinase, phosphorylating the RLC (22). Sweeney, Bowman and Stull (48) discovered that this RLC phosphorylation is associated with an enhanced RFD within fast-twitch skeletal muscle. The researchers suggested that the mechanism behind this involves the moving of the myosin cross bridges away from the thick filament backbone within the skeletal muscle. Regarding the secondary mechanism, tetanic isometric contraction in animals results in an increased transmittance of excitation potentials across synaptic junctions at the spinal cord (18). When an action potential travels through an axon, it arrives at the pre-synaptic terminal. The action potential releases neurotransmitters into the synaptic space that then bind to receptors on the post-synaptic terminal of the next axon. Research has shown an increase in post-synaptic potentials, for the same pre-synaptic potential during any subsequent physical activity (28). Furthermore, research has demonstrated a decreased transmitter failure in subsequent activity following tetanic contractions (49). Luscher et al (28) suggested that monosynaptic transmitter failure is greater at larger motor neurons; the ones that control activation of higher order motor units. Luscher and colleagues (28) discovered a significant PAP effect at specific larger motor neurons that was a result of the decreased higher order motor neuron recruitment. However, this research has been conducted within animals and it is still yet to be discovered within human subjects.

Furthermore, there are multiple factors that can affect the PAP response. The strength level of the individual largely determines the volume and intensity of the PAP protocol (45). With stronger individuals requiring repetition maximal loads and fewer sets in comparison to weaker individuals requiring multiple sets and a lower intensity (45). Research has found stronger athletes to display a larger and faster PAP response than weaker individuals (45,46). Previous research has classified > 2 x body mass back squat as strong and below as weak (46). It is thought that this is due to stronger individuals having a greater fatigue resistance in comparison to the weaker individuals (4, 20). However, an issue with the literature is that there are no universal guidelines to classify an individual as strong or weak but more related to an individual's training experience.

The literature shows that within skeletal muscle, there is a co-existence of fatigue and PAP (7). Performance enhancement is dependent on how potentiated the targeted muscles are and the degree to which fatigue has dissipated (30, 42, 53). Following the PAP protocol, a level of fatigue is created which results in the athlete having a decreased force and power output (15, 18). This was likely due to the athletes not having sufficient recovery time for adenosine triphosphate (ATP) and PCr re-synthesis and therefore retaining the muscles in a fatigued state as opposed to a potentiated state (45). Highlighting the requirement for individualised recovery times as opposed to a set time for all. This is important as the individual's strength level and the type of conditioning activity undertaken will dictate the length of recovery required (45).

In relation to swimming, Sarramian, Turner and Greenhalg (44) investigated the use of box jumps (41cm) with 10% of subject's bodyweight wearing a weighted vest and pull-ups on 50m freestyle performances. No significant performance enhancement was found with the researchers acknowledging that the PAP method used was not specific to the kinematics of the upper limb movement during the race. Kilduff et al (26) found similar results when investigating the effect of a PAP intervention on swimming block starts. The PAP intervention involved using the traditional back squat exercise prior to a timed swim to 15m. Although no significant performance enhancement was discovered, the researchers found a significant increase in vertical jump height following the PAP intervention, thus displaying the neuromuscular effects PAP has. Therefore, it could be suggested that although a neuromuscular effect occurred, either the timed distance was not long enough to express the PAP effects or the PAP intervention was not specific enough to provide a performance enhancement. Due to the specificity issues with PAP protocols, studies have investigated the use of in-water protocols (1, 21). Hancock, Sparks and Kullman (21) investigated using dynamic resistive sprints of 10m, 4 reps with a one-minute inter-rep rest on 100m freestyle performance. Following the PAP protocol, performance was significantly faster (0.54s) in comparison to the control trial. However, Barbosa and colleagues (1) did not find any performance enhancing effect following an in-water PAP protocol involving the completion of 8 x 12.5m efforts using paddles and a parachute. Although the protocol used by Barbosa et al involved a greater volume in comparison to Hancock et al (21), thus creating more fatigue, and requiring additional recovery which may explain the found results.

The majority of the literature investigating PAP has used traditional high intensity exercises such as the back squat, bench press and pull-ups (5, 13, 25, 26, 44, 46, 54) along with in-water resisted swimming drills for swimming performance (1, 21). As previously stated, FINA Rule SW 3.2.5 requires all swimmers to report to the call room no later than 20 minutes prior to their race. As such, the completion of traditional exercises such as the back squat and in-water protocols are not possible due to the equipment required and pool access (54). Therefore, any PAP protocol used within a swimming competition must require little to no equipment thus allowing the athlete to complete a PAP protocol within the call room.

One method that has received little research as a PAP protocol is plyometrics. Turner, Bellhouse, Kilduff and Russell (52) investigated the effects of a plyometric protocol prior to completing 20m sprints with 10m splits. The protocol involved performing three sets of 10 alternate leg-bounds with either bodyweight only or with additional weight (10% bodyweight). The results displayed improvements in both 10m and 20m times in the plyometric protocol with additional weight following 4 and 8-minute recovery times in comparison to the control trial. Although no electromyography was recorded, the alternate leg bounding used was associated with the predominant recruitment of type II muscle fibres and maximal activation of associated musculature (9). Both of which play key roles for inducing PAP, based on previously explained mechanisms (22). Therefore, due to zero equipment requirements a plyometric protocol may better suit a swimmer in competition.

Another potential strategy that could be used within the 20-minute call room time period is the use of passive heat maintenance protocols post warm up (10, 35, 40). Passive heat maintenance methods include the use of survival jackets and heated clothing to attenuate heat loss (40). The primary aim of the warm up is to increase the body's core temperature $T_{Core}$ for a series of temperature related mechanisms to occur (2). The literature displays findings of enhanced performance with an increased $T_{Core}$ (2, 10, 11, 37, 43).

Sargeant (43) discovered that by increasing a muscles' temperature ($T_M$) by one degree Celsius, maximal peak force and power output could increase between 2 and 11%. The work undertaken by Sargeant (43) also discovered how a decrease in $T_M$ could result in a decreased maximal peak force and power output of up to 21%. Both $T_M$ and $T_{Core}$ decline immediately following the completion of the warm up, with research by Mohr et al (37) displaying significant reductions following 15-20 minute recovery periods. As such, there is the potential for the use of passive heat maintenance strategies to ameliorate the decline in $T_{Core.}$

Faulkner et al (10) investigated the use of different passive heat maintenance strategies on sprint cycling performance. The subjects completed time trials using insulated athletic pants and insulated athletic pants with integrated electric heating elements (IHEAT). The results displayed a decreased $T_M$ in all trials following the post warm up recovery period. However, a smaller decline in $T_M$ occurred in the IHEAT trial in comparison to the other trials. The performance results showed a significantly larger peak power output in the IHEAT (1609 ± 270W) in comparison to the control trial (1468 ± 260W) and the insulated athletic pants trial (1545 ± 338W). The researchers concluded that minimising the $T_M$ decrease following the warm up improved sprint cycling performance.

Within swimming, McGowan et al (35) investigated the use of heated jackets and activation exercises on 100m freestyle performances. In two of the four trials, the subjects wore a tracksuit jacket with heating elements over the pectoralis major, latissimus dorsi and quadratus lumborum regions along with a t-shirt and conventional tracksuit bottoms. These heating elements were set to 51°C. The activation exercises were designed to mimic the limb movements within swimming and involved medicine ball throw downs, box jumps and a simulated underwater butterfly kick whilst in a streamlined position. The researchers discovered that in comparison to the control trial (60.70 ± 3.36s), 100m freestyle performances were significantly faster in the trial that utilised both the passive heat maintenance strategy and activation exercises (59.90 ± 3.70s) and in the trial that saw the subjects complete only the activation exercises (60.26 ± 3.50s). With regards to the subject's $T_M$, there was a decreased $T_{Core}$ in all trials during the transition phase. There was less of a decline however in the trial using the heat maintenance strategy and activation exercises (-0.13 ± 0.25°C). An important finding was the correlation between 100m freestyle time and $T_{Core}$. The researchers reported faster performance times with smaller $T_{Core}$ declines ($R^2$ = 0.91). The results and literature demonstrate the requirement and performance enhancement for ameliorating the $T_{Core}$ decline following the warm up. The results from this study also indicate the need for activation exercises in addition to a passive heat maintenance strategy. Completing activation exercises within the transition period whilst in the call room not only acts as a dynamic re-warm up but can also be used to induce a PAP response within a swimmer. West et al (55) has previously found performance enhancements in rugby union players when combining a passive heat maintenance strategy and a PAP protocol.

A limitation to the work conducted by McGowan et al (35) is that the subjects only wore a tracksuit jacket with heated elements. The lower limbs have a significant affect on swimming performance and it could be suggested that the subjects within this study may have seen a further performance enhancement if heated tracksuit bottoms were used. Additionally, there is an issue with the financial costing of the heated jackets, whereby many non-funded athletes are unable to purchase these.

In light of the above, the use of a plyometric protocol to induce a PAP response and a passive heat maintenance method as a pre-race strategy may be logistically and physiologically beneficial for swimmers. Therefore, the aims of this study were to firstly discover whether the completion of a plyometric protocol alone or along with the use of passive heat maintenance enhanced 100m freestyle performances. A secondary aim was to determine the correlation between $T_{Core}$ and 100m freestyle performance. We hypothesised that utilising plyometric exercises to induce a PAP response along with the use of passive heat maintenance to maintain the elevated $T_{Core}$ following the pool warm up would result in a faster 100m freestyle performance, in comparison to a seated, passive recovery.

## METHODS

### Experimental approach to the problem

The investigation followed a counterbalanced study design to control order effects. Subjects initially completed two familiarisation sessions, with a plyometric protocol being completed within one of these sessions (Table 2). Following the plyometric protocol subjects completed one countermovement jump (CMJ) immediately post and at 2, 4, 6, 8 and 10 minutes post to individually determine the optimal recovery time for enhanced lower limb power output.

The subjects completed four different main experimental trials within the simulated 20 minute call room time period. In one trial subjects completed the plyometric protocol (PLYO) at individualised times prior to a 100m freestyle time trial. Another trial completed saw the subjects complete the plyometric protocol along with the use of a blizzard heat jacket as a method of passive heat maintenance pre time trial (PHEAT). A third experimental trial involved the use of only the blizzard heat jackets prior to the 100m freestyle time trial (HEAT). A fourth, control trial (CONTROL) involved the subjects undertaking passive rest pre time trial to discover the effectiveness of the pre race strategies measured in the other experimental trials on 100m freestyle performance.

### Subjects

Twelve national (6 males, 6 females) standard swimmers volunteered to undertake the investigation. The participant's ages ranged from 13 to 22 and anthropometric characteristics can be found in Table 1. Written consent was obtained from the athletes and the parents or guardians of swimmers that were under eighteen years of age in accordance with University Ethical regulations. Ethical approval was obtained from the University Ethics Committee prior to data collection. The swimmers were informed of the risks and benefits of taking part and were informed that they could withdraw from the study at any time they wished to. All swimmers trained 6 times a week in the pool and completed two land based strength-training sessions a week. Each swimmer had a minimum of twelve months of resistance training experience that involved plyometric training. The swimmers were instructed to abstain from caffeine, alcohol and strenuous exercise within the 24 hours prior to the main experimental trials.

Table 1. Anthropometric characteristics and 100m freestyle performance times of subjects *(n=12).*

| Characteristics | Mean ± SD |
|---|---|
| Age (yr) | 15.5 ± 2.4 |
| Body mass (kg) | 63.4 ± 9.2 |
| Height (cm) | 162 ± 9.1 |
| Best 100m freestyle performance (s) | 57.30 ± 2.73 |

**Procedures**

Prior to the main experimental trial being undertaken, subjects completed two familiarisation sessions within one week. During the first familiarisation session subjects completed a CMJ to assess lower limb power. This was completed prior to the subjects undertaking the plyometric protocol (Table 2). When performing the CMJ, subjects were instructed to keep their hands on their hips, look forward and jump as high as possible following a counter movement squat. Each subject then performed one CMJ jump immediately post completion of the plyometric protocol and then at 2, 4, 6, 8 and 10 minutes post respectively. This was to determine each individual's optimal recovery time for enhanced lower limb power. Within the second familiarisation session, the subjects completed one baseline CMJ prior to undertaking their individualised land based dynamic warm up. CMJ heights were then recorded immediately post and then at 2, 4, 6, 8 and 10 minutes post. This was to ensure that the CMJ did not cause a fatigue or warm up effect. The CMJ heights were measured using the Just Jump System (Probiotics Inc, Hunstville, USA). The following correction equation was used for its overestimation of jump height; Jump height (cm) = (0.8747 x jump height given by console) – 0.0666 (36).

Table 2. Plyometric protocol adhered to during the study.

| Exercise | Reps | Sets |
|---|---|---|
| Pogos | 5 | 2 |
| Single leg alternate bounding | 10 metres | 2 |
| Single leg hops | 5 each leg | 2 |
| Depth jump from 12 inch plyometric box | 3 | 2 |

The main experimental study was completed over a two-week period between 4-6pm and was comprised of four trials, each separated with a minimum of 48 hours to allow for complete neuromuscular recovery. The subjects acted as their own controls and completed each of the four trials in a randomised, double blind manner. Within each of the trials the subject's tympanic body temperature was recorded at rest, within one minute post pool warm up and within one minute prior to their timed swim. A Braun ThermoScn (IRT 4520, Braun GmbH, Kronberg, Germany) was used to measure tympanic temperature. The Braun ThermoScan has been found to provide both valid and accurate readings for core body temperature (3, 14). In all four trials, the subjects completed a standardised pool warm up (Table 3). Ten minutes was then provided for physical recovery and for the subjects to change into their race suits. Following this ten-minute period, the subjects entered a simulated call room for 20 minutes prior to completing the 100m freestyle time trials in order to simulate the procedures at a competition.

Table 3. Standardised pool warm up completed by subjects.

| Drill | Distance (M) | Reps |
|---|---|---|
| Freestyle stroke | 200 | 2 |
| Freestyle skill | 50 | 1 |
| Freestyle stroke distance | 50 | 1 |
| Freestyle kick – speed bursts | 50 | 1 |
| Freestyle sprint | 50 | 1 |
| Freestyle pacing | 20 | 2 |

Participants completed four different experimental trials within the 20-minute period in the simulated call room (Figure 1). During CONTROL, the subjects were instructed to remain seated in their normal clothing for the 20 minutes before their timed swim. Within PLYO, the subjects completed the plyometric protocol (Table 2) prior to completing the timed swim. Each subject completed the plyometric protocol at his or her individualised time to allow for an optimum recovery time period. In HEAT, the subjects remained seated within the simulated call room whilst wearing a survival heat jacket (Optimum Sportswear full length coverall and Blizzard Protection Systems Ltd, Gwynedd). The jacket was put on immediately post changing into their race suits and remained in the jackets until at the blocks for the timed swim. Within the remaining trial the subjects wore survival heat jackets in the same procedure as in the HEAT trial, and also completed the plyometric protocol at their individual time to allow for individualised optimal recovery prior to the timed swim (PHEAT). Due to equipment availability time trials were timed using a Finis Stopwatch 3X-300M (SKU 1.300.40 DRB-E5) by the same person who was blind to the procedures throughout data collection..

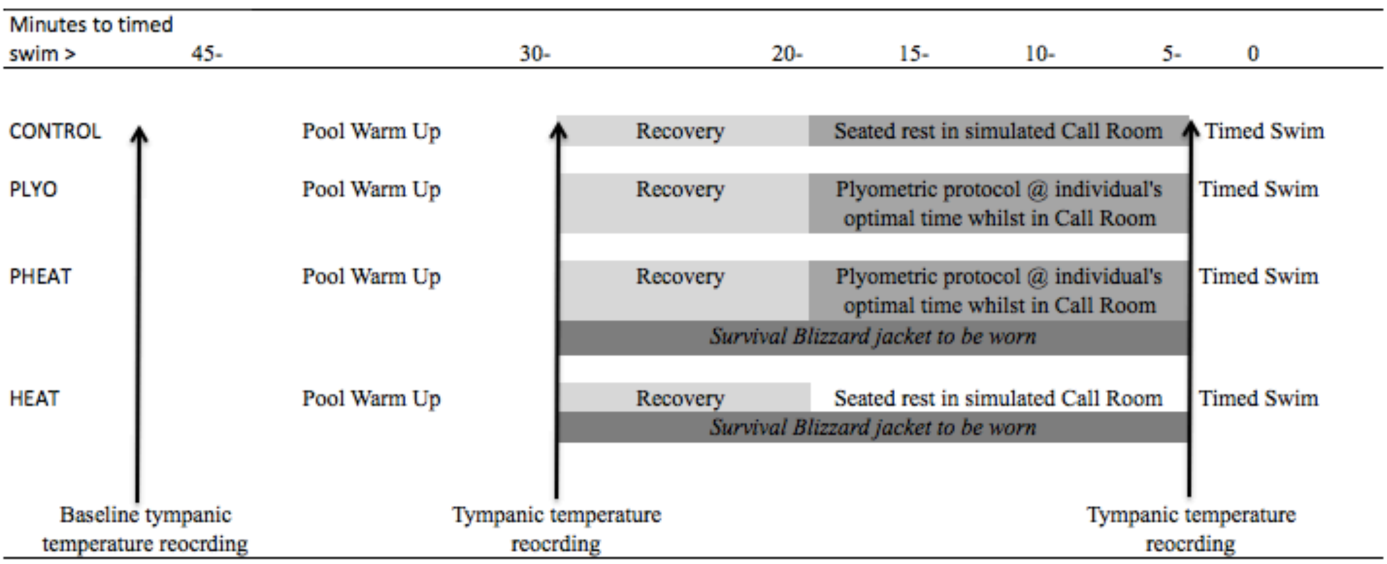

Figure 1. Schematic of the study protocol adhered to during the four main testing sessions.

### Statistical Analyses

The data was tested for normality and presented as mean ± SD. To discover any significant effects of the independent variables on 100m freestyle performances, a repeated measure ANOVA was conducted comparing the data from the PLYO, PHEAT, HEAT and CON trials. The data was analysed as a group and was then split into males and females to establish any gender differences. Thus process was also repeated for 15m and 50m time splits.

Spearman's correlation coefficient tests were carried out to distinguish the relationship between pre race core body temperature and race performance in each of the four trials. Again, the data was analysed as a group and split into males and females to discover any variation between sexes. The statistical analysis of all data was completed using the SPSS software (version 22; SPSS Inc., Chicago, USA). The significance level was set at $p \leq 0.05$ for all statistical tests.

## RESULTS

### 100m swimming performance

Repeated measures ANOVA of the swimming times displayed a statistically significant difference ($F$ (2.330, 25.633) = 8.109, $p < 0.005$) between the four trials (Figure 2). The 100m freestyle times were fastest in PHEAT (56.33 ± 2.86s). Using the Bonferroni adjustments, post hoc tests revealed a significant interaction difference ($P = 0.009$) between PHEAT and CONTROL (56.33 ± 2.86s vs. 57.48 ± 2.57s respectively). Following additional Bonferroni adjustments, post hoc test analysis found significant time effects ($P = 0.029$) in PLYO vs. CONTROL (56.95 ± 2.78s vs. 57.48 ± 2.57s respectively). Statistical analysis also discovered significantly faster times in PHEAT compared to HEAT ($P = 0.038$) (56.33 ± 2.86s vs. 57.26 ± 3.09s). The post hoc tests did not discover any significant time differences between PHEAT and PLYO ($P = 0.380$), PLYO and HEAT ($P = 0.538$) and between HEAT and CONTROL ($P = 1.000$).

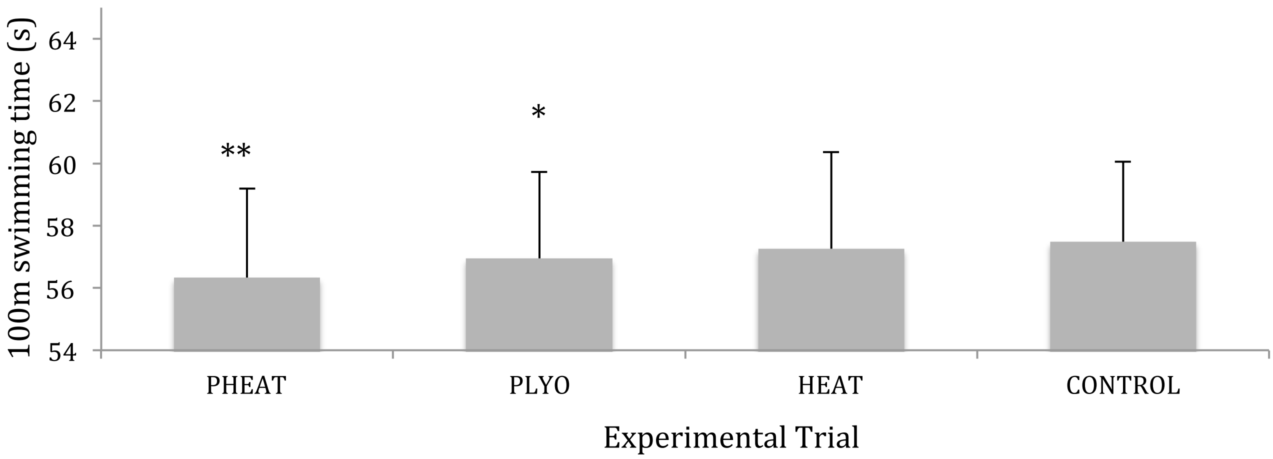

Figure 2. Mean ± SD 100m freestyle race times for all subjects in the experimental trials. *Indicates significantly different CONTROL. **Indicates significantly different to CONTROL and HEAT.

Analysis of swimming performance between genders found no significant difference in 100m times across the trials for females ($P$>.05) (Table 4). However, a significant difference was found between the PHEAT and CONTROL trials for the males ($P = 0.033$). No significant differences were found between the other trials.

The fastest times to 15m were found in PHEAT (6.38 ± 0.49s) in comparison to PLYO (6.49 ± 0.53s), HEAT (6.67 ± 0.61s) and CONTROL (6.59 ± 0.44s). Statistical analysis of 15m, both genders combined, using repeated measures ANOVA discovered a significant difference ($F$ (2.383, 26.215) = 6.572, $p < 0.005$) between PHEAT and CONTROL ($P = 0.011$) and PHEAT and HEAT ($P = 0.028$). In comparison, statistical analysis of the subjects' 50m times found no significant time differences between the four trials ($F$ (1.837, 20.202) = 0.977, $p > 0.005$).

**Core Body Temperature**

Repeated measures ANOVA discovered no significant difference in the subject's $T_{Core}$ immediately pre time trial between the four experimental trials ($P = 0.651$). Although no significant difference was found, the data displayed the greatest mean change in $T_{Core}$ from baseline to immediately pre time trial in the HEAT trial (0.66°C) in comparison to PHEAT, PLYO and CONTROL (0.62°C, 0.41°C and 0.46°C respectively) (Figure 3).

Table 4. Comparison of male and female time trial times and core body temperatures.

| Trial | PHEAT | | PLYO | | HEAT | | CONTROL | |
|---|---|---|---|---|---|---|---|---|
| Gender | Female | Male | Female | Male | Female | Male | Female | Male |
| 15m time (s) | 6.69 ± 0.33 | 6.08 ± 0.44 | 6.73 ± 0.42 | 6.26 ± 0.56 | 7.10 ± 0.29 | 6.24 ± 0.54 | 6.85 ± 0.31 | 6.33 ± 0.42 |
| 50m time (s) | 28.76 ± 0.56 | 26.62 ± 1.85 | 29.08 ± 0.80 | 26.49 ± 1.15 | 29.49 ± 0.73 | 26.52 ± 1.24 | 29.05 ± 0.81 | 26.90 ± 1.17 |
| 100m time (s) | 59.29 ± 0.57 | 54.36 ± 1.70 | 59.46 ± 0.31 | 55.28 ± 2.33 | 60.23 ± 0.42 | 55.28 ± 2.32 | 59.93 ± 0.12 | 55.85 ± 1.98 |
| Baseline tympanic temperature (°C) | 36.5 ± 0.37 | 36.4 ± 0.48 | 36.7 ± 0.53 | 36.5 ± 0.29 | 36.6 ± 0.31 | 36.4 ± 0.49 | 36.5 ± 0.45 | 36.8 ± 0.26 |
| Post warm up tympanic temperature (°C) | 35.1 ± 0.59 | 34.8 ± 0.60 | 34.7 ± 0.62 | 34.6 ± 0.16 | 35.0 ± 0.66 | 34.5 ± 0.32 | 35.1 ± 0.37 | 34.5 ± 0.49 |
| Pre time trial tympanic temperature (°C) | 37.05 ± 0.34 | 37.08 ± 0.21 | 37.07 ± 0.38 | 36.98 ± 0.25 | 37.00 ± 0.41 | 37.32 ± 0.13 | 37.08 ± 0.34 | 37.12 ± 0.31 |

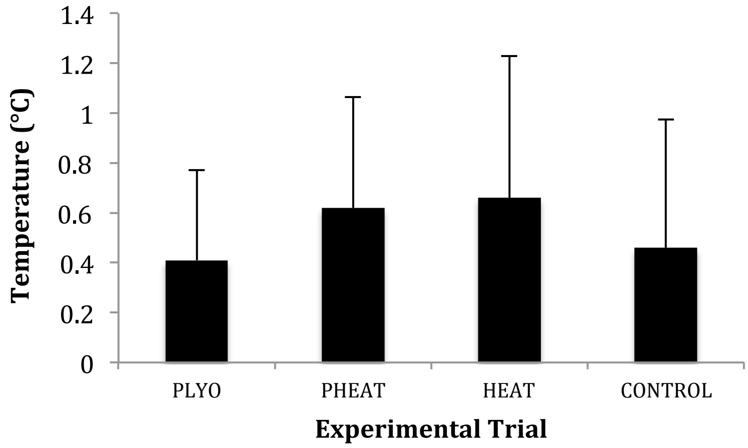


Figure 3. Core body temperature increases from baseline to immediately pre time trial. Values are presented as mean ± SD.

Furthermore, in all experimental trials the data displayed a decreased $T_{Core}$ post pool warm up in comparison to baseline $T_{Core}$ recordings. The data showed a mean non-significant decrease of 1.8°C in $T_{Core}$ at post warm up recordings in all four trials (Figure 4).

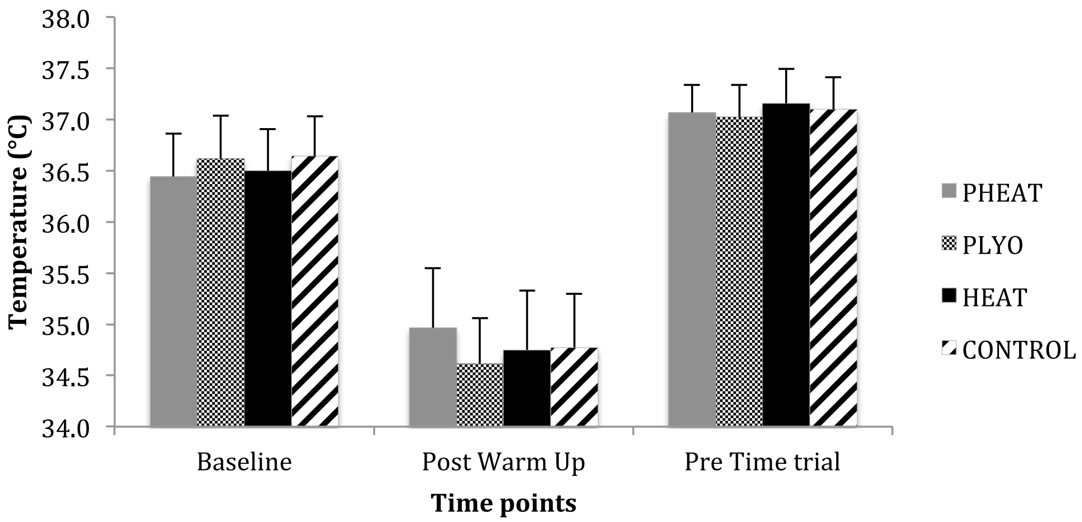


Figure 4. Mean ± SD core body temperatures at the three time points in all trials.

In regards to the relationship between $T_{Core}$ and 100m freestyle swimming times, a Spearman's correlation test discovered negative correlations between $T_{Core}$ and 100m freestyle performances in all four experimental trials (PHEAT $r_s$ = -0.0.43, $P$ = 0.894; PLYO $r_s$ = -0.110, $P$ = 0.734; HEAT $r_s$ = -0.647, $P$ = 0.023; CONTROL $r_s$ = -0.219, $P$ = 0.493). The test found a significant correlation in the HEAT trial ($P$ = 0.023) with all other trials displaying no significant correlations (Figure 5). Similar results were found with regards to the 15m and 50m times. Whereby only the HEAT trial displayed a significant correlation both in 15m and 50m times ($r_s$ = -0.641, $P$ = 0.025, $r_s$ = -0.647, $P$ = .023 respectively).

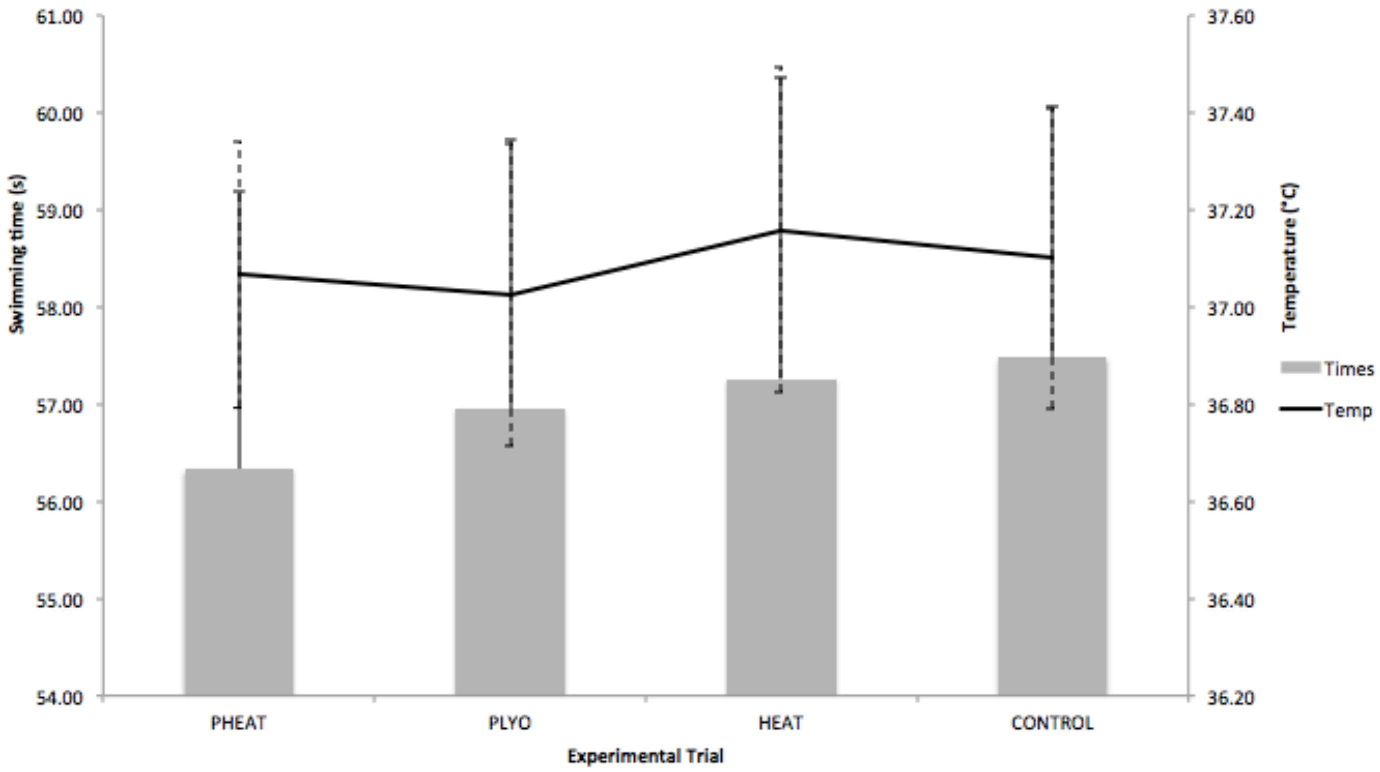


Figure 5. Mean ± SD 100m freestyle times with mean ± SD core body temperatures immediately pre time trial. * indicates a significant correlation between 100m freestyle time and $T_{Core}$ immediately pre time trial.

## Discussion

The primary aim of the study was to discover the ergogenic effects of completing a plyometric protocol alone or in combination with a passive heat maintenance strategy. The results of the study show that 100m freestyle swimming performance can be enhanced when a plyometric protocol and passive heat maintenance strategy are used pre race, with greatest performance enhancements found when the two strategies are used in combination, which is in agreement with previous research (35).

The 100m freestyle times were significantly faster in PHEAT in comparison to the CONTROL and HEAT trials. A time difference of 1.15s between the mean PHEAT and CONTROL trial times is a substantial margin within competitive swimming, given the difference between first and eighth place at the

2016 Olympics in the men's 100m freestyle was 0.83s. Therefore, these results pose a significant addition to the current literature investigating methods to enhance swimming performance.

PHEAT and PLYO displayed the fastest 100m freestyle times. This is an important finding as it displays the significant ergogenic effect of undertaking the plyometric PAP protocol pre race. However, as previously stated, race times in PHEAT were faster than in all other trials, indicating the additional importance of the passive heat maintenance strategy. A similar discovery was made by McGowan et al. (35) whereby the researchers found the fastest 100m freestyle times when an activation protocol involving medicine ball throw downs, box jumps and a simulated underwater butterfly kick whilst in a streamlined position was combined with a passive heat maintenance strategy. Although non-significant, the subjects mean $T_{Core}$ in the present study was 0.04°C higher in PHEAT than in PLYO immediately pre time trial. The blizzard heat jackets enabled the subjects to ameliorate the $T_{Core}$ decline within the call room time period, thus providing one explanation to the faster 100m times in PHEAT compared to PLYO. An elevated $T_M$ has been shown to increase ATP turnover rate (11, 16, 17). Subsequently, this increases enzyme activity that then causes increased adenine nucleotide degradation and an increase in key glycolytic enzymes, thus augmenting anaerobic glycolysis (11). Additionally, an increased $T_M$ has been found to increase energy contribution from the anaerobic pathway and an increased muscle fibre conduction velocity (11, 16, 17). Therefore, maintenance of an elevated $T_M$ post warm-up can affect subsequent performance (2).

To the researcher's knowledge, this study was the first to investigate the effects of a plyometric protocol on 100m freestyle performances. The two trials involving the plyometric protocol yielded the two fastest mean 100m times, both being significantly faster than the CONTROL trial (Figure 2). The results of the current study are in agreement with existing literature investigating the effects of a plyometric protocol on subsequent explosive activity (51, 52). Although no electromyography recordings were taken in the present study, it can be suggested that the plyometric protocol successfully induced a level of PAP within the subjects. Plyometric exercises such as the single leg alternate bounding undertaken in the present study involve the recruitment of type II muscle fibres (9) and these recruitments may play a role in inducing a PAP effect based on the underlying mechanisms of PAP (22). The mechanism as to what causes a PAP effect following a single plyometric protocol is still unknown. One potential mechanism may be an increased compliance of the tendon allowing the muscle to produce force closer to its optimal length. This is typically a chronic adaption to plyometric training. However, in support with previous research a single plyometric bout may find the same acute responses (51).

The plyometric protocol also acted as an active re-warm up during the transition period whereby the swimmers are in the call room. An active warm up has been found to be more beneficial for performance in comparison to a passive warm up (2). In addition to the temperature related effects of the warm up, an active warm up produces additional short-term ergogenic effects (2). Firstly an increased oxygen delivery to the working musculature is seen by means of an increased blood flow. This is caused through a reduction in oxygen tension (33), increase in potassium concentration (24) and hydrogen ion concentration (19) resulting in vasodilation. Secondly, an elevation of the baseline oxygen consumption levels. This allows the individual to begin an activity with an increased $\dot{V}O_2$ and therefore a decreased oxygen deficit (34), sparing the anaerobic capacity for later in the activity. This is substantial as within the 100m freestyle race, the length of time to complete the race displays its predominant anaerobic contribution to energy source.

The start times (time to 15m) were significantly faster in the PHEAT trial in comparison to the CONTROL and HEAT trials. The second fastest times were in the PLYO trial, although not significantly faster. The 50m times recorded found no significant differences between the trials, suggesting the plyometric protocol had its greatest influence within the first 15m. A plyometric protocol requires as little as 0.3-4 minutes of recovery for a performance effect to be found (45). However, there is currently no research indicating the length of time the performance enhancement effect remains. Based on the results of the current study, it can be suggested that the PAP effect obtained from the plyometric protocol had a negligible effect on performance in the last 75m of the time trial. This is still significant however, with the start times contributing up to 30% of overall race times (31).

In regards to gender, the results displayed no significant differences in 100m times between the four trials for females (*P* > 0.05) and only a significant difference was discovered between PHEAT and CONTROL for males (*P* = 0.033). One explanation for the found results may be due to the strength levels of the subjects. As previously discussed, stronger individuals display a larger and faster PAP response, requiring fewer sets/ reps in comparison to weaker individuals (45). The plyometric protocol may not have had enough reps and sets to induce a PAP response within the females, indicating that the females were not relatively strong enough to display a performance enhancing PAP effect. However, in support of previous literature, the bodyweight plyometric protocol in the present study demonstrates that a PAP protocol does not require heavy loading to induce PAP (52, 54). The present results do however suggest that maximal activation of the musculature is required. It also provides swimming athletes with a logistically viable option of inducing PAP and improving performance.

The results of the current study found no significant differences in $T_{Core}$ immediately pre time trial between the four experimental trials, despite previous research finding a smaller decline in $T_{Core}$ following a warm-up when passive heat maintenance strategies were used (10, 35). This finding may provide reasoning as to why no significant time effects were found between HEAT and CONTROL. Furthermore, when comparing $T_{Core}$ to 100m freestyle swimming times, there were no positive correlations in any of the trials (PHEAT, *P* = 0.894; PLYO, *P* = 0.734; HEAT, *P* = 0.023; CONTROL, *P* = 0.493). This was an unexpected finding as previous research has discovered a positive correlation between $T_{Core}$ and explosive activity performance. McGowan and colleagues (35) found that by reducing the decline in $T_{Core}$ subsequent swimming performance was enhanced. Furthermore previous work by Sargeant (43) discovered that by increasing a muscles' temperature by one degree Celsius, power output increased between 2 and 11% in subsequent performance. One explanation for this finding may be due to the blizzard heat jacket used within the present study. The blizzard jacket was successful in minimising the decline in the subject's $T_{Core}$ during the call room period. However in comparison, McGowan et al (35) used a heated jacket that had heating elements incorporated into the jacket with the elements set to 51°C. The disadvantage of this is its practicality to most swimmers who are not of the elite, funded level. The blizzard heat jacket was chosen in this study for its practicality by swimming athletes of all levels. However, following this study, the tracksuit jacket with heated elements used by McGowan et al (35) appears to be a superior option of maintaining $T_{Core}$. Although the blizzard heat jacket used in the current study was successful in minimising the decline in $T_{Core}$ during the call room period.

An additional unexpected result from the present study was the decline in $T_{Core}$ immediately post pool warm up in all four experimental trials (Figure 5). The average decrease in the four trials was 1.8°C. In comparison, $T_{Core}$ has been found to increase by approximately 0.7 ± 0.1°C following a 25 minute pool warm up (35) and by 0.8 ± 0.3°C (54). One explanation for this could be heat loss due to convection whilst the individual is in the water (5). It can be hypothesised that as an individual remains still in water, their body heat increases the temperature of the water in close proximity to themselves. However, as the individual moves in the water the boundary layer of warmer water surrounding the individual is disturbed. Therefore, as a larger volume of water flows over the skin due to propulsion, a larger volume of body heat is lost through convection (5). Why this finding was not found in the previous literature could be due to the intensity of which the subjects were swimming, with previous research involving a higher intensity warm up (35).

A key difference of the present study in comparison to the literature was how there was no upper body exercises incorporated into the PAP protocol. McGowan and colleagues (35) involved medicine ball throw downs, along with Sarramian et al (44) using maximum repetition pull-ups and medicine ball throw downs. Both of these studies found significantly faster swimming performances. Furthermore, research has demonstrated the predominant contribution of the upper limbs to propulsion within freestyle swimming (8). However, Sarramian et al (44) stated how the use of an upper body exercise to induce a PAP effect was not appropriate on its own due to the contribution from the lower limbs to forward propulsion. Therefore, following the successful results of the present study through the utilisation of a lower body plyometric protocol, investigating the combining of lower body plyometric exercises with upper body ballistic exercises may discover greater performance enhancements within the 100m freestyle races.

One possible limiting factor to the present study may have been the strength levels of the subjects. Given the subject's age range (15.5 ± 2.4) and resistance training experience, some of the individuals may not have been physically strong enough or possess the number of type II fibres for a true representation of the acute effects of a plyometric protocol. In regards to type II fibres, the literature explains how adolescents possess fewer in comparison to adults and how stronger individuals possess a greater volume in comparison to weaker individuals (27, 32). This has been associated with an increased phosphorylation of the myosin light chain (38), which being one of the primary mechanisms of PAP displays the significance of type II fibres (22). Furthermore, the literature has found how a single bout of plyometric exercise predominantly results in damage to type II muscle fibres, highlighting their recruitment during plyometric exercises (29). Ensuring individuals possess the strength to fully display the effects of plyometric exercises should be incorporated into future research.

Additionally, the present study was limited to only the freestyle stroke. It could be hypothesised that the lower limb plyometric protocol in the current study may have had a superior performance effect within the breaststroke. With the literature discovering forward propulsion in the breaststroke to be lower limb dominant in comparison to the freestyle stroke being upper limb dominant (8, 39). Future research investigating the effects of the plyometric protocol on the breaststroke is suggested.

To conclude, this study demonstrated how 100m freestyle swimming performances could be significantly enhanced when a plyometric exercise protocol is completed alone or with a passive heat maintenance strategy. Consequently, the hypothesis of this study was accepted. However, the findings displayed no positive correlations between $T_{Core}$ and 100m freestyle swimming performances.

## Practical Applications

Due to FINA rule SW 3.2.5 stating that all swimmers must report to the Call Room no later than twenty minutes prior to the start of their event, the findings of the current study highlight how the incorporation of a plyometric protocol at a specific time pre-race significantly enhances 100m freestyle performance as opposed to a seated recovery. Performance can be further enhanced when a passive heat maintenance strategy is used in combination with the plyometric protocol. A mean time difference of 1.15s was discovered between undertaking the combined plyometric protocol and passive heat maintenance strategy trial in comparison to a seated recovery. Therefore, providing swimming athletes with a logistically practical method of acutely enhancing 100m freestyle performance. Further research is warranted to investigate the incorporation of upper body ballistic exercises in addition to lower body plyometric exercises and passive heat maintenance strategies.

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